APPENDIX 4.6

Energex LV fusing program

Energex

LV Fusing Program

Asset Management Division

energex

positive energy

Energex

LV Fusing Program 2015/16 - 2019/20

Reviewed:

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Version control

Version	Date	Description
1	13/05/15	Initial version authored by C Lee
2	15/05/15	Revised after feedback from P Price
3	19/06/15	Revised by C Lee and R Fedrick

Energex Limited (Energex) is a Queensland Government Owned Corporation that builds, owns, operates and maintains the electricity distribution network in the growing region of South East Queensland. Energex provides distribution services to almost 1.4 million domestic and business connections, delivering electricity to a population base of around 3.2 million people.

Energex's key focus is distributing safe, reliable and affordable electricity in a commercially balanced way that provides value for its customers, manages risk and builds a sustainable future.

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Table of Contents

1 Executive Summary

The LV fusing program involves the installation of low voltage high rupturing fuses on pole mounted transformers. The objectives for the low voltage (LV) fusing program are:

1) Provide adequate protection for LV faults and ensure safe outcomes to the community

2) Comply with the ENA National Low Voltage Protection Guidelines; and

3) Reduce the safety risk for a low voltage fault incident to ALARP.

Energex embarked on the LV fusing program in 2010 with an initial installation of around 400 per annum to allow for deployment of work practices, training of staff and enabling of work program efficiencies. This ramped up to a targeted rate of 2000 installations by the end of 2012/13 with a completion date around 2019/20.

Energex conducted a safety risk assessment of the program in 2013/14 and to achieve ALARP, it was decided to accelerate the program to a rate of 3269 installations per annum, so that the remaining 10,000 transformers can be completed in 3 years, by 2017/18.

The revised proposal to the AER for funding of $23.4M for the first 3 years of the 2015-20 regulatory period is the same as the original proposal (refer table below).

Forecast Expenditures and Installations in AER Period					
	15/16	16/17	17/18	18/19	19/20
Revised Proposal	$23.4 Mill (3269 sites)	$23.4 Mill (3269 sites)	$23.4 Mill (3269 sites)	Nil	Nil

2 Strategy for the LV Fusing Program

2.1 Background

Energex conducted a review of its LV protection standards and guidelines in 2008 following the release of the ENA National Low Voltage Protection Guidelines (in 2006). In the review, Energex also conducted a survey of major utilities in Australia and found that the industry best practice as applied in utilities in New South Wales (Energy Australia and Country Energy), Victoria (PowerCor, Alinta and Agility) and Queensland (Ergon Energy) were to install LV fuses on all pole mounted transformers. Energex at the time only installed LV fuses on the smaller rated single phase transformers and three phase transformers up to 63 kVA.

Details of the review conducted by Energex in 2008 (reference SEG-08-09) are given in Attachment 1.

A covering memo approving the implementation of LV fusing on transformers 100 kVA and above is given in Attachment 2.

The recommendations in the approval memo were:

1) ENERGEX change its low voltage protection philosophy to align with the industry standard in Australia and in line with the ENA low voltage protection guidelines and introduce low voltage fusing across all transformer sizes.

2) The change in the Standard to be applied at the distribution transformer on all new overhead low voltage feeders or where there is an upgrade of the transformer or there is a re-conductoring of the low voltage conductor

3) ENERGEX undertake a retrofit program to upgrade low voltage fusing on existing transformers.

2.2 Details of Current LV Fusing Program

For the retrofit program, there was an anticipated 20,000 transformers rated at 100 kVA and above which required the LV fuses to be installed. In order to achieve a cost effective outcome for the program, it was initially decided to install only a single fuse at the transformer. The program started in 2010 with an initial rate of 400 per annum (to ensure that the work crews could replace the fuses in an efficient manner along with other work on the pole) and this was intended to be ramped up to 2000 transformers per annum. At the end of 2013/14 there was around 4200 of the transformers had been completed. It was then anticipated that at the rate of 2,000 per annum, it would take a further 7 to 8 years to complete the program.

A further review of the LV fusing program was conducted in 2012/13 (refer Attachment 3) to determine whether there was a better arrangement for protection of the low voltage network to further extent the protective length. There had been a number of incidents where LV pillars fed off overhead networks at a distance from the transformer had caught on fire and were not cleared by the transformer low voltage protection.

The outcomes of the review were as follows:

1) Install dual fuses on transformers 200 kVA and above – to achieve a longer protective reach of the LV fuses

2) Install transformer monitors in lieu of Maximum Demand Indicators (to assess voltage and safety issues on the LV network)

In 2013/14, Energex reviewed the risk assessment based on the expected program completion date. The risk assessment indicated the need to complete the LV fusing program in a reasonable timeframe i.e within 10 years of the publication of the ENA low protection guidelines in 2006.

One safety initiative which Energex had considered was the introduction of LV bonding (when working de-energised) which is in practice in NSW, Victoria, South Australia and Western Australia. Following a trial and risk assessment it was identified that for the LV bonding practice to be effective, the installation of LV fuses would be required to pick up and clear faults along the LV circuits.

2.3 LV Fusing Program – Current and Forecast Program

Table 1 shows the number of transformers which have been upgraded with LV fuses over the period 2009/10 to 2013/14.

Table 1 – Current Progress with LV Fusing Program

LV Fuse Installations per Annum					
09/10	10/11	11/12	12/13	13/14	14/15
1	399	820	1064	1973	3269

The forecast numbers for the period 2014/15 is shown in Table 2. The increase to 3,269 has occurred in the 2014/15 and expected to remain at this level for 3 years of the next AER period.

Table 2 – Forecast Progress with LV Fusing Program

Forecast Expenditures and Installations in AER Period					
	15/16	16/17	17/18	18/19	19/20
Revised Proposal	$23.4 Mill (3269 sites)	$23.4 Mill (3269 sites)	$23.4 Mill (3269 sites)	Nil	Nil

Note: Transformers which are replaced or upgraded have the LV fusing standard applied and are not included in the above installations or forecasts

2.4 Risk Management

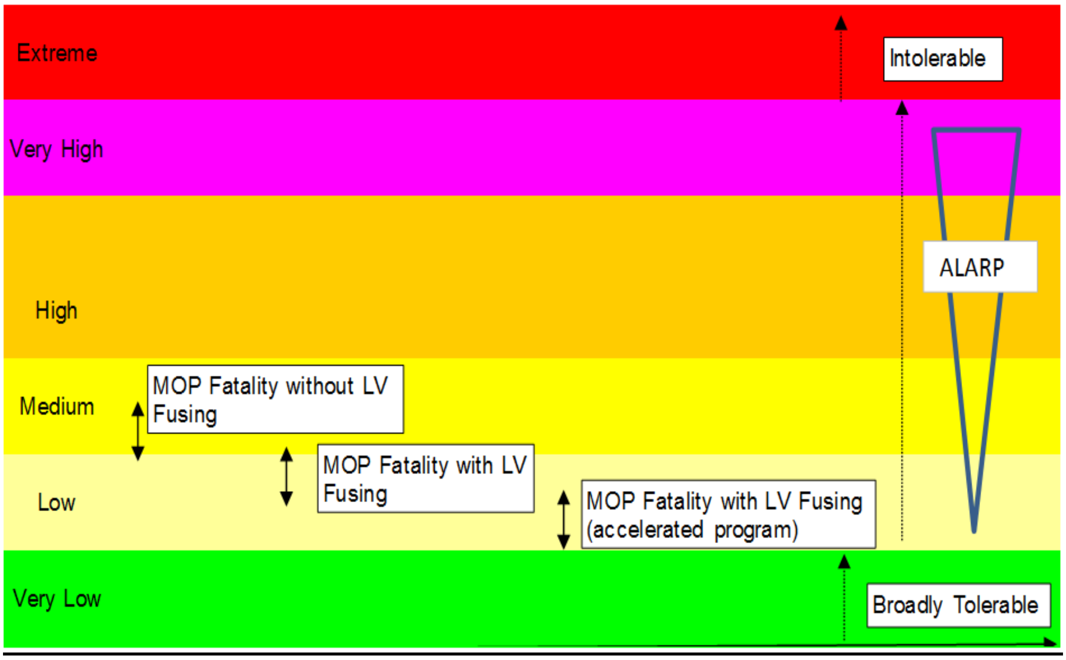
The acceleration of the LV fusing to 4 years was subject to a formal risk assessment. The risk assessment conducted on 10 May 2013 considered 2 risk scenarios as follows:

1) A member of the public (MOP) makes contact with an energised low voltage wire on the ground.

2) A crew working on urban LV mains isolates and tests and <u>bonded</u> but becomes inadvertently energised and a member of public contacts a fallen live LV mains outside work area and receives a fatal shock

The Risk Evaluation's for the MOP scenarios are shown in Figure 1.

Figure 1 – Risk Assessment for Various Scenarios



The risk assessment investigated the current state with the up to 15,000 pole mounted transformers without LV fusing and evaluated the risk as being **Medium Risk**. The next risk assessment considered progress with low voltage fusing (installing fuses on 2000 transformers a year for the next seven years), and then accelerating the program to get them done in 3-4 years instead. With the accelerating of the program, the risk score reduced from **Medium Risk** to **Low Risk**, which is considered to be **ALARP**.

2.5 Conclusions and Project Justification

The key drivers and justification for the LV fusing program are:

1) To address public safety risks (from a fallen LV conductor which is not protected)

2) To comply with the ENA low voltage protection guidelines (published in 2006)

3) To meet industry practice for LV fusing

4) To provide improved protection (increase in protective length) to address incidences such as pillars on fire

Energex has intense summer storms which can cause a high number of wires down (typically in the hundreds for a major storm event). With no LV protection or limited HV protection, a substantially number of LV wires may be left energised. This poses a high safety risk to the community.

The ENA low voltage protection guidelines were published in 2006 and Energex has endeavoured to implement LV fusing on pole mounted transformers in a reasonable timeframe of 10 years. It will also align Energex with what is industry practice for protection of LV circuits.

Energex has taken a sound and efficient approach with the introduction of an LV fusing program in 2008/09. The initial program was to install the fuses over an approximate 10 year period, with 2000 being installed per annum.

The initial installation were around 400 per annum to allow for work program efficiencies and this ramped up to 2000 per annum in 2012/13, with approximately 4,200 installations completed by 2013/14. A review conducted at time indicated that it would take a further 7 years to complete the program. A risk assessment was conducted to provide justification for an acceleration of the program from 7 years to 4 years.

There have been LV faults which have not been detected by current protection (such as pillar fires) and the LV fusing program coupled with ensuring LV circuits are designed with protective cover, will assist Energex's endeavours in improving community safety.

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Systems Engineering Memorandum

To	Scott Jamieson - Group Manager Systems Engineering
From	Colin Lee - Network Systems Development Manager
Copies	Johnathon Khor – Network Substations Standards Manager Roy English – Network Engineering Standards Manager Paul Rainbird – Group Manager Network Reliability and Maintenance Shane Kerr – Protection Engineering Manager
Date	1 May 2008 **Reference** SEG-08-09
Subject	**REVIEW OF FUSE PROTECTION ON DISTRIBUTION TRANSFORMERS AND LOW VOLTAGE FEEDERS**

1.0 CURRENT STATUS OF FUSE PROTECTION OF 11 KV DISTRIBUTION TRANSFORMERS AND OVERHEAD LOW VOLTAGE FEEDERS IN ENERGEX

In ENERGEX, the 11 kV / 415 Volt pole mounted distribution transformers are protected by Expulsion Dropout (EDO) fuses on the 11 kV side of the transformer. For transformers of less than 100 kVA, there are additional fuses installed on each of the outgoing low voltage circuits.

The primary function of the 11 kV EDO fuses is to clear faults in the transformer and associated circuits, but for the larger transformers of 100 kVA and higher, the EDO fuses provide fault protection for the outgoing low voltage circuits. The EDO also provides a secondary function of overload protection on the transformer. Where possible the fuse rating has been selected to handle the maximum anticipated transformer load which is 1.5 times the transformer nameplate rating. For example, for a 200 kVA transformer which has a full load current of 10.5 amps, the fuse size is 20K.

This criteria does not however apply to the transformers rated at or below 100 kVA. The fuse rating has been standardised across the range of transformer sizes at 8T. The purpose of the larger fuse rating is to prevent nuisance operation of the fuses due to lightning surges.

One of the drawbacks of the larger EDO fuses on the transformers rated at or below 100 kVA is the limited capability for protecting phase to phase and phase to ground faults on the low voltage circuits. Low voltage fuses of the high rupturing current type (HRC) are required to be installed on all the outgoing low voltage feeders to ensure adequate protection of the low voltage feeders.

Low voltage fuse protection is also provided on all underground cables and overhead bundled cable circuits (LVABC). Fuses are provided on underground cables to prevent damage to the insulation from a sustained fault. The fuse protection for the LVABC is provided to protect the cable from thermal overloads which may affect the integrity of the insulation and cause the cable to slip out of the terminations.

The relevant standards for 11 kV EDO and low voltage fuses are:

- AS1033 – "High voltage fuses (for rated voltages exceeding 1000 V)"
- AS60269 – "Low voltage Fuses"

The current selection guide for 11 kV EDO fuses and LV HRC fuses is shown in Table 1 (extract from Technical Instruction TSD0019C).

Table 1 – 11 kV EDO and LV Fuse Selection for Transformers

11 kV EDO Fuse & LV Fuse Selection For Transformers						
Transformer Rating (kV.A)	Full load (A)		11 kV EDO Fuse (▲) - Fuse class		LV HRC Fuse (Legend of notations 2 pages over)	
	11kV	LV	Fuse Type	Stock Code	Fuse Type	Stock Code
SWER						
10	1.6	42	3K	13401	(♦) 50/80A	04442/04451
25	3.9	104	3K	13401	(B) 80A (O) 100A	04451 12454
Single phase						
10	0.9	40	8T	14228	(♦) 50/80A	04442/04451
25	2.3	100	8T	14228	(B) 80A (O) 100A	04451 12454
Three Phase						
15	0.8	20	8T	14228	(♦) 50/80A	04442/04451
25	2.3	33	8T	14228	(B) 80A (O) 80A	04451 04451
50/63	2.6/3.3	67/87	8T	14228	(B) 80A (O) 100A	04451 12454
100	5.2	133	8T	14228	(B) 200A/(O)Links (GT) 125A	13898 / - 16284
200	10.5	267	20K	13405	(B) 200A (O) Links	13898 -
315	15.7	400	25K	13730	(B) 200A (O) Links	13898 -
500	26.2	667	40K	13731	(O) Links	
750	39.4	1000	50K	13732	bolted	
1000	52.5	1333	63/65K	13733	bolted	
1500	78.7	2000	80K	13734	bolted	
NOTE	**Replace All Three Phase Fuses!**					

Note: (B) designates LV ABC conductor, (O) designates open wire construction. (GT) ground transformers

2.0 ENA NATIONAL LOW VOLTAGE PROTECTION GUIDELINES

In general, fusing for power distribution transformers is based primarily on the need for the HV fuses to detect faults in the HV and LV windings, LV cabling and LV busbars and also on considerations of rating and grading with LV fuses [Ref 1].

The most recent version of the ENA National Low Voltage Protection Guideline [Ref 2] was released in March 2006. The principles outlined in this guideline are:

<u>For overhead lines</u>

"Overhead distributors shall be designed and incorporate electrical protection designed to clear a bolted fault, such as, wires twisted or firmly held together by fallen tree branches."

<u>For underground cables</u>

"All parts of underground distributors shall incorporate electrical protection designed to both clear bolted faults and prevent damage being caused by the associated through fault current. It is not practicable to provide protection for some short teed distributor sections (nominally not exceeding 150m and rated at 100 Amps or less), however the risk posed by such sections is considered acceptable."

A bolted fault is defined as having *"zero contact resistance at the point of the fault"*.

ENERGEX has previously developed guidelines on the maximum length of run for the low voltage feeder to properly coordinate with the low voltage service fuses for some of the standard type of conductors in use. Table 1 was extracted from a previous Substation Design Standard and this gives the maximum length of conductor between the LV fuse and the transformer for a 1 second clearing time and a bolted fault.

Table 1 – Maximum Length of 7/4.75 AAC Low Voltage Conductor between the Transformer and Service Fuse

TFR RAT-ING (kVA)	FAULT LEVEL ON HV SIDE (MVA)	FAULT CURRENTS FOR BOLTED PH-PH AND PH-G FAULTS AT THE LV TERMINALS				MAXIMUM LENGTHS (km) OF 7/4.75 AAC (7/.186) LV CONDUCTOR WHICH CAN BE CONNECTED BETWEEN THE TRANSFORMER AND SPECIFIED LV FUSE FOR <u>1 SECOND</u> CLEARING TIME OF BOLTED PH-PH AND PH-G FAULTS (CURRENT REQUIRED FOR A PRE-ARCING TIME OF 1 SECOND APPEARS IN BRACKETS BELOW EACH FUSE SIZE). SEE NOTES 1 AND 2																				MAXIMUM LENGTH OF LV MAINS (km) PROTECTED BY THE TRANSFORMER FUSE (See Note 3)	
		CURRENT ON LV SIDE (AMPS)		CURRENT SEEN ON HV SIDE (AMPS)		50 A (300)		63 A (350)		80 A (500)		100 A (700)		200 A (1300)		250 A (1700)		400 A (2800)		500 A (3600)		630 A (5000)		800 A (6800)		CURRENT FOR PRE ARCING TIME OF 1 SEC (AMPS)	LENGTH FOR WORST FAULT (km) (See Note 3)
		PH-PH FAULT	PH-G FAULT	PH-PH FAULT	PH-G FAULT	PH-PH FAULT	PH-G FAULT	PH-PH FAULT	PH-G FAULT	PH-PH FAULT	PH-G FAULT	PH-PH FAULT	PH-G FAULT	PH-PH FAULT	PH-G FAULT	PH-PH FAULT	PH-G FAULT	PH-PH FAULT	PH-G FAULT	PH-PH FAULT	PH-G FAULT	PH-PH FAULT	PH-G FAULT	PH-PH FAULT	PH-G FAULT		
1 ph 10	10	-	298		7		0.0																			300 A @ LV	-
25	10	-	679	-	16	-	0.5	-	0.35	-	0.15															700 A @ LV	See note 4
3 ph 15	10	380	443	17	10	0.3	0.3																			350 A @ LV	0.1
25	10	619	728	28	17	0.75	0.5																			350 A @ LV	0.4
50	10	1078	1285	49	29	1.05	0.7	0.85	0.53																	500 A @ LV	0.3
100	50	2504	2934	114	67	1.3	0.8	1.1	0.7	0.7	0.45	0.45	0.3													50 A @ 11 kV	0.05
200	50	4799	5700	219	130	1.4	0.85	1.15	0.75	0.8	0.5	0.55	0.35	0.25	0.15											110 A @ 11 kV	0.05
300	50	6763	8128	308	185	1.4	0.85	1.2	0.75	0.8	0.5	0.55	0.35	0.25	0.15	0.2	0.1									130 A @ 11 kV	0.05
500	100	10567	12587	482	287	1.45	0.9	1.2	0.75	0.85	0.5	0.6	0.35	0.3	0.2	0.2	0.15	0.1	0.1							200 A @ 11 kV	0.05
750	100	11326	13521	516	308	1.45	0.9	1.2	0.75	0.85	0.5	0.6	0.35	0.3	0.2	0.2	0.15	0.1	0.1	0.1	0.05					280 A @ 11 kV	0.05
1000	100	12452	14916	568	340	1.45	0.9	1.2	0.75	0.85	0.5	0.6	0.35	0.3	0.2	0.2	0.15	0.1	0.1	0.1	0.05	0.05	0.05			350 A @ 11 kV	See Note 4
1500	100	14133	17015	644	388	1.45	0.9	1.2	0.75	0.85	0.5	0.6	0.35	0.3	0.2	0.2	0.15	0.1	0.1	0.1	0.05	0.05	0.05	0.05	0.05	450 A @ 11 kV	See Note 4

1. Fuse time-current characteristics used: 20 SWG, 32 A, 50 A, 63 A, 80 A, 100 A - SEQEB drawings: SK 24/81-A4, SK 25/81-A4
All others - A curve midway between minimum pre-arcing and maximum total operating times in AS 2005 Part 2.

2. All lengths are to the nearest 50 m.

3. • In the case of transformers rated at 50 kV.A and below, the transformer fuse is an LV fuse while for transformers rated above 50 kV.A it is an 11 kV expulsion dropout fuse.
• Maximum length of LV mains (km) protected by the transformer fuse.

4. No PH-G faults will be cleared in under one second for these cases. (PH-G terminal faults shall be cleared in under 1.5 seconds.)

5. To enable faults to be cleared adequately, do not exceed the length of conductor for respective fuse/transformer size.

In reality there will always be a contact resistance at the point of the fault. Low voltage faults often involve tree branches applying pressure to the conductors or wildlife bridging conductors, thereby causing phase to phase or phase to neutral faults to occur. To cover situations where there is a finite contact resistance the ENA guideline goes on further to say:

"*As it is not possible for electrical protection on LV distributors to detect some faults, such as LV arcing faults or wires on the ground, alternative means of risk mitigation must be considered and adopted such as:*

- *develop training material for emergency services personnel and police when attending fallen power-lines,*
- *provide training to emergency services personnel and police,*
- *periodically issue media releases/public safety awareness information to reinforce or improve the public awareness of the hazards of fallen power-lines,*
- *provide electricity customers with electrical safety information such as pamphlets with electricity bills,*
- *the use of insulated conductors in place of bare conductors,*
- *the adoption of new technology when commercially viable."*

ENERGEX has implemented a number of these measures already.

3.0 BACK UP PROTECTION FOR LOW VOLTAGE FUSES AND COMPARISION WITH CIRCUIT BREAKER PROTECTION

The ENA Low voltage protection guideline discusses the performance of fuses and compares with alternative protective devices such as miniature circuit breakers. Section 6.7 of the guideline mentions:

The unique "fail-safe" nature of LV fuses makes backup unnecessary. Fault current limiting (FCL) fuses are used extensively in LV electricity networks because of their consistent reliable performance.

Fuse protection also has the following disadvantages, which should be considered in risk assessments and protection design:

- *LV fuses only operate to clear a single phase at a time. This can result in equipment remaining back-energised even though fault current is not flowing.*
- *Due to their thermal nature, the operating time/current characteristic of a fuse varies more than that of some circuit breakers in the low fault current or overload regions.*
- *Fuses cannot provide earth fault protection in the same way as circuit breaker / relay systems.*

Circuit breakers and relay systems may fail to operate and therefore may require back-up protection. The need for back up protection shall be determined by the application of risk *management. The analysis should include but not necessarily be limited to consideration of the following:*

- *The reliability of the circuit breaker*
- *Maintenance frequency*
- *Consequences of failure to operate*
- *Consequences and likelihood of HV fuses operating below their minimum breaking current.*
- *Operational environment*
- *Design of circuit breaker and its relay system*

Fuses and circuit breakers operating in enclosures or in high temperature environments may need to be derated.

4.0 LOW VOLTAGE PROTECTION PRACTICES ADOPTED BY OTHER UTILITIES

4.1 Survey of other Utilities

Table 2 gives the results of a survey which was conducted on low voltage fusing practices in other utilities.

Table 2: Survey of Low Voltage Fusing Practice in other Utilities

Utility	Low Voltage Fusing for Transformers at 100 kVA and above	Low Voltage Fusing for Transformers Below 100 kVA
ENERGEX	No	Yes
Ergon Energy	Yes	Yes
Energy Australia	Yes	Yes
Country Energy	Yes	Yes
PowerCor	Yes	Yes
Alinta and Agility	Yes	Yes

Although the survey only covers a small number of the Australian utilities, the practice of fusing for low voltage feeders for all of the distribution transformers sizes appears to be widespread throughout Australia.

4.2 Cost / Benefit Justification for Adopting Low Voltage Fusing Protection at Ergon

When Ergon Energy was formed there were different practices adopted in the regional areas of Queensland. The northern regions (Far North Queensland and North Queensland) did not provide low voltage fusing on the larger transformers but the rest of the state applied low voltage fusing on all transformers.

Ergon undertook a review of the low voltage protection and found there were significant benefits in adopting low voltage fusing for the larger transformers and now have a policy of fusing all sizes of transformers. The benefits found by Ergon were:

- Prevention of damage to transformers from thermal overloads (Ergon experienced thermal overload on transformers following cyclones when the LV conductors were wrapped around each other and were not cleared by the EDO fuses)
- Prevention of damage to LV circuits from faults at the end of these runs that are not cleared quickly by the HV protection
- Extends the protective reach on the low voltage circuits for bolted faults
- Ensure that Ergon is seen as doing all that was reasonable with regards to public safety

5.0 BENEFITS FOR THE INTRODUCTION OF LOW VOLTAGE FUSE PROTECTION ON LARGER TRANSFORMERS IN ENERGEX

5.1 Improvement in Public Safety

There have been incidences where low voltage phase to earth faults have not been cleared by 11 kV EDO fuses with a consequence of substantial property damage. One particular instance occurred in 2003 at Norman Park where a wind blown palm frond caused an A phase to neutral fault. The transformer supplying the low voltage circuit was a pole mounted 200 kVA transformer with 20 A type K EDO fuses. The fuse is expected to melt with 40 A fault current (1800 A on the low voltage side) in around 5 minutes. The calculated fault current in this instance was only 1100 A, hence the reason why the EDO did not clear the fault.

The fault current caused the A phase and neutral conductors to weld together and the sustained fault current caused neutral connections on bridges to be badly damaged. A number of houses (up to 13) suffered property damage, particularly at the switchboard and the earth connections (where the high earth fault current flowed to ground). A number of loss of supply/ dim lights were reported at the time of the fault and the crew isolated the transformer about 80 minutes after these reports to limit the damage.

If there was a low voltage HRC fuse installed at the transformer or down the low voltage circuit, then it is likely that the neutral and the houses may not have suffered any damage. This will be investigated later.

5.2 Protection of transformer from overload in situations where there are uncleared low voltage faults

Ergon Energy has experienced thermal overload on transformers following cyclones when the LV conductors were wrapped around each other and were not cleared by the HV fuses.

Low voltage phase to phase faults which generate high fault currents will usually be cleared in a short time by the EDO fuses to minimise damage. Low voltage faults which generate low fault currents, such as phase to earth, tend to have some contact resistance (eg tree branch or wildlife) and this will significantly reduce the fault currents to below the overload capability of the transformer.

In addition, ENERGEX has implemented a number of measures to ensure that phase to phase and phase to ground faults on the low voltage network is kept to a minimum, such as:

(1) routine vegetation management practices (cutting on a 2 to 3 year cycle and pre-summer storm patrols)
(2) installing mid span low voltage spacers to avoid conductor clashing
(3) audit of the network by the ESO from time to time. When vegetation is putting pressure on low voltage conductors which could then cause a fault, the ESO will issue an improvement notice and this will cause an immediate cut of the vegetation.

It is however concluded that low voltage fuse protection on the transformer can offer some degree of overload protection on the transformer for uncleared bolted faults on the low voltage circuit.

6.0 COST BENEFIT FOR THE INTRODUCTION OF LOW VOLTAGE FUSE PROTECTION ON LARGER TRANSFORMERS IN ENERGEX

6.1 Additional cost for low voltage fuses

If low voltage fusing is introduced for the larger transformers, there are 2 options to fuse the outgoing open wire circuits. One option involves the installation of only one set of LV fuses at the transformer, the other option is to install separate fuses on all of the outgoing low voltage circuits. The estimated cost for the installation of a set of low voltage fuses are as follows:

3 x Single phase fuse holders - $225 (3 x $75)
Fuses - $75 (3 x $25)
Installation cost - $360 (2 men x 1.5 hr x $120 /hr)
Planning and Proj Management - $60

Total cost - $720

The incremental cost for the first fuse unit is however much less than this because the current standard has disconnect links at the transformer. It will only be a matter of installing a switch fuse unit instead of a disconnect link. The cost of installing the fuses would be around $100.

The benefits with the installation of separate fuses on all of the outgoing low voltage circuits is in terms of reliability and reduction in clearing times. If the low voltage customers on the distribution substation are supplied via 2 circuits, then when a fault occurs, only half of the customers will be without supply. If there is a critical customer supplied off the distribution transformer it may be advantageous to have separate fused circuits so that a fault on the other circuit does not cause loss of supply to the critical customer.

In general, when fusing separate LV circuits, the fuse size can be reduced. For example, if it is usual for a 400 A LV fuse to be specified for a single case on a 315 kVA transformer, then it may be acceptable to use a 250 A fuse where there are multiple LV circuits. In terms of improvement in clearing times (refer to Figure 3), a fault current of 1000 A will be cleared in 1 minute with a 400 A fuse and only 3 seconds with a 250 A fuse.

6.2 Requirement to ensure grading of 11 kV and low voltage protection

If low voltage fuses are to be introduced for the larger distribution transformers, then there will need to be discrimination applied between the 11 kV EDO's and the low voltage HRC fuses. Otherwise, in the event of a fault on a low voltage circuit, both sets of fuses will operate and will need replacement.

Figures 1 to 2 show the fuse characteristic of Type T (slow operation) and Type K (fast operation) EDO fuses. The EDO fuses have a characteristic which is similar to an Inverse Definite Mean Time (IDMT) overcurrent type relay. A low voltage fuse has a much faster clearing time as shown by the volt time characteristic in Figure 3.

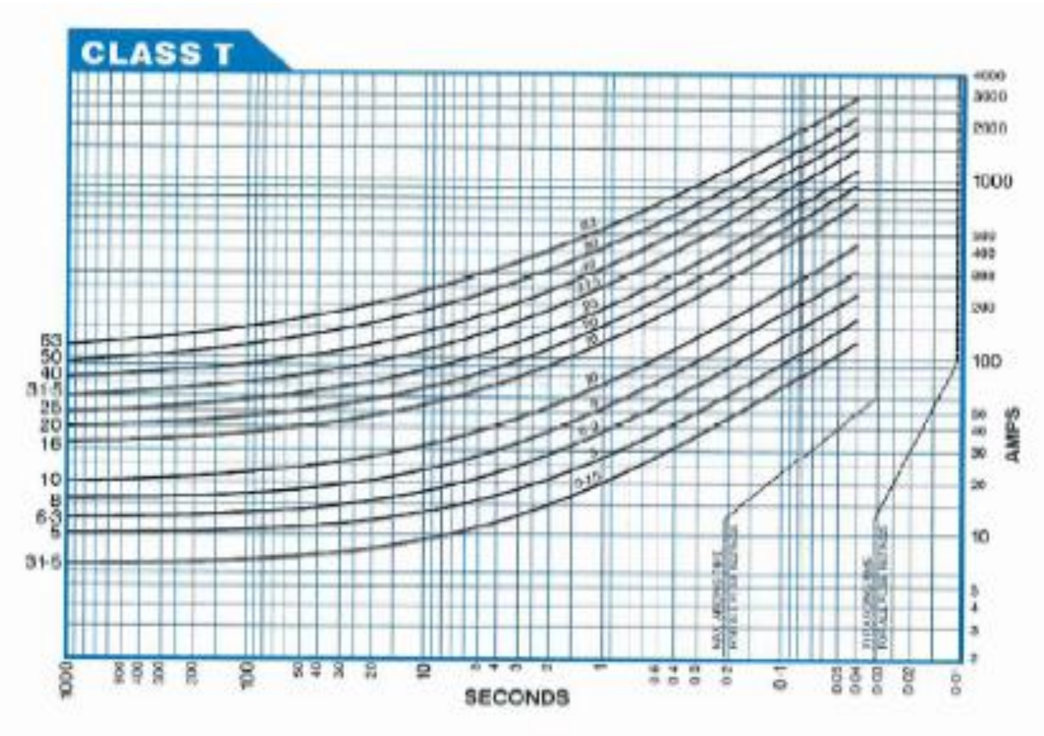

Figure 1 – EDO Class T Volt vs Time Operating Characteristic

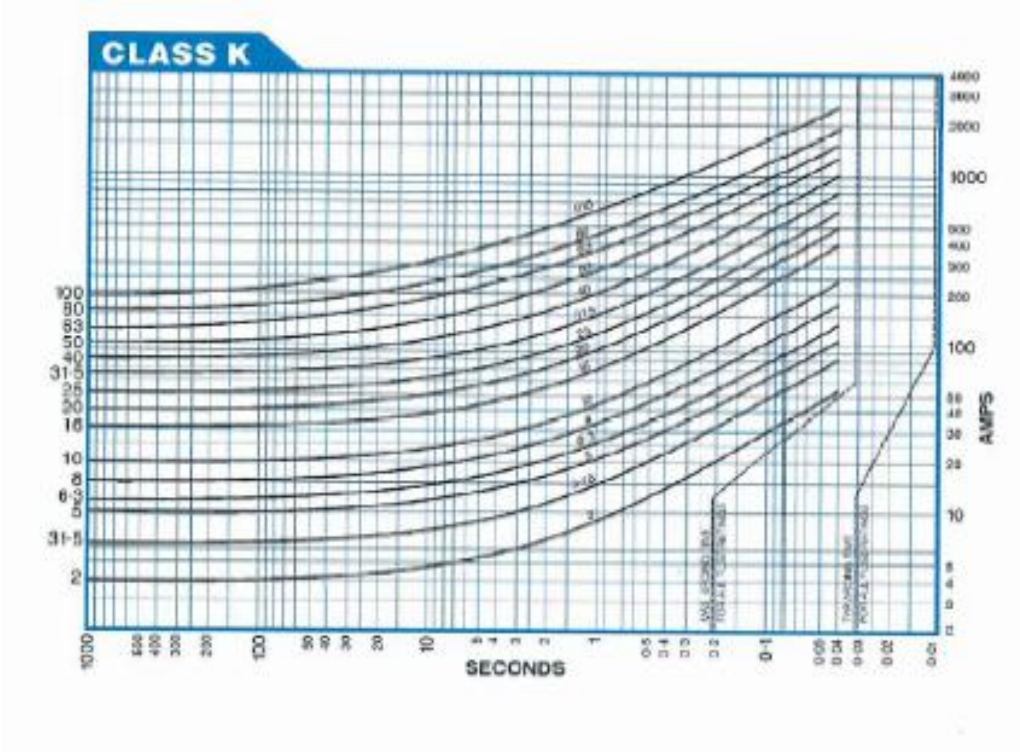

Figure 2 – EDO Class K Volt vs Time Operating Characteristic

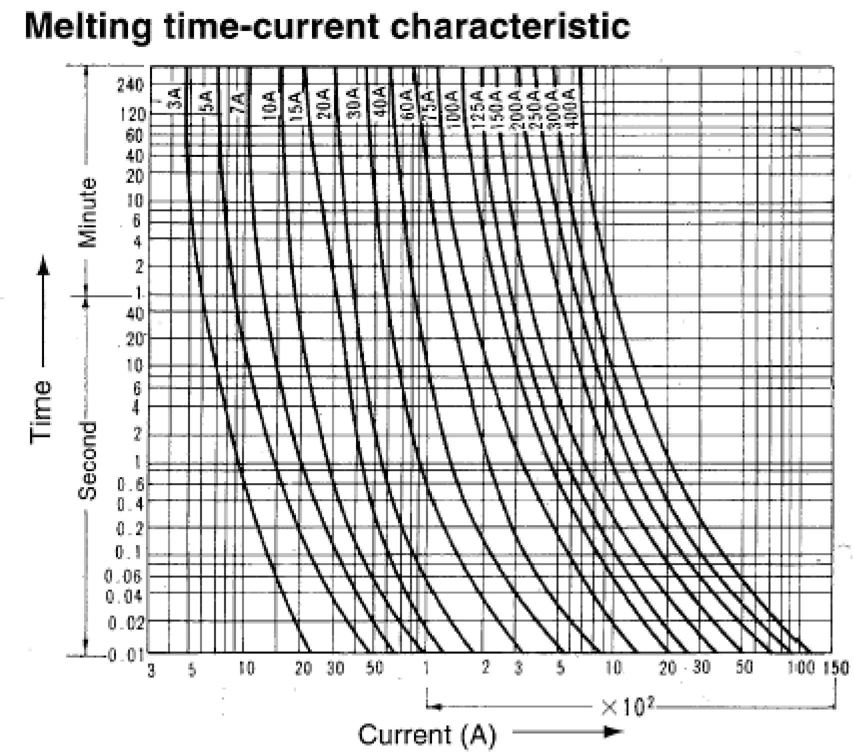

Figure 3 – Low Voltage HRC Volt vs Time Operating Characteristic

An extract from Ergon Energy's Overhead Distribution Transformer Overcurrent Protection Guidelines is given in Table 2.

Ergon Energy has found the need to increase the size of the 11 kV EDO fuse when LV fusing is introduced. For instance for a 100 kVA transformer, when there is no LV fusing, the EDO size is 10 K. When LV fusing is introduced, the fuse size increases to 16 K. For a 315 kVA transformer, the EDO fuse is increased from 25 K to 31.5 K.

The drawback with the increase in fuse size, is that the EDO fuses will operate in a slower time and this will allow more damage to occur on the transformer and it's associated components (terminations, cabling etc).

Table 2 – Ergon's Overhead Distribution Transformer Overcurrent Protection Guidelines

11/22/33kV HIGH VOLTAGE									
Transformer		11kV TRX HV Fuse - Fault Level ≤ 8kA Expulsion Dropout Fuses (Note 1)				11kV TRX HV Fuse - High Fault Level > 8kA Current Limiting Fuses (Note 2)			
		with TRX LV Fuse		without TRX LV Fuse		with TRX LV Fuse		without TRX LV Fuse	
		HV Fuse Link	I.I. No.	HV Fuse Link	I.I. No.	HV Fuse Link	I.I. No.	HV Fuse Link	I.I. No.
10	1 ph.	3/10K	2400566	--	--	6A	2404162	--	--
25	1 ph.	6/20K	0620158	--	--	8A	0104607	--	--
50	1 ph.	16K	0620087	--	--	12A	0621109	--	--
25	3 ph.	3/10K	2400566	--	--	6A	2404162	--	--
50	3 ph.	6/20K	0620158	--	--	8A	0104607	--	--
63	3 ph.	6/20K	0620158	--	--	8A	0104607	--	--
100	3 ph.	16K	0620087	10K	0620079	18A	0104606	12A	0621109
200	3 ph.	25K	2400568	16K	0620087	25A	0104608	18A	0104606
300	3 ph.	31.5K	0620109	25K	2400568	30A	0104609	25A	0104608
315	3 ph.	31.5K	0620109	25K	2400568	30A	0104609	25A	0104608
500	3 ph.	50K	0620125	40K	0620117	40A	0104610	40A	0104610

6.3 Requirement to ensure distribution transformers are not overloaded

There is a general requirement that the LV fuses must not cause thermal overloading on the transformer and should be sized to handle the maximum loading on an LV circuit. In the case of a 100 kVA transformer, the current rating of the transformer is 140 A. From Table 1, the fuses which are installed on the ENERGEX LV network are 200 A for the LVABC and 125 A for ground transformer which supply underground cabling.

7.0 IMPROVEMENTS OPPORTUNITIES IN FUSING PRACTICES AT ENERGEX

7.1 Installation of LV fuses on pole mounted transformers rated at 100 kVA to 500 kVA

The general philosophy for the selection of fuse ratings for a given size transformer is shown in Appendix 2. These philosophies were obtained from documentation supplied by Country Energy and Energy Australia.

Table 3 gives a comparison of the Distribution Transformer fuse selections between Ergon and Country Energy based on the installation of LV HRC fuses on the larger transformer sizes. The comparison shows the following:

- In general the 11 kV EDO fuse sizes have increased by between 25% and 50% (excepting the 100 kVA transformer, where the fuse size has been doubled)
- Country Energy allow for fusing on all LV circuits (Multi) or fusing only at the transformer (Single)
- Country Energy's low voltage fuse sizing is much lower than Ergon's because they are prepared to accept LV fuses to be rated at 95% of the nominal output of the transformer

Table 3 – Revised Distribution Transformer Fuse Selection with LV HRC fuses

11 kV EDO Fuse & LV Fuse Selection For Transformers						
Transformer Rating (kVA)	**Full load (A)**		**11 kV EDO Fuse**		**LV HRC Fuse**	
	11 kV	**LV**	**Ergon**	**Country Energy**	**Ergon**	**Country Energy**
Three Phase						
100	5.2	133	16 K	16 K	(B)200, (O) 160	(O) 125
200	10.5	267	25 K	20 K (Mult) 31.5 K (single)	(B) 200, (O) 355	(O) 160 (M) (O) 250 (S)
315	15.7	400	31.5 K	31.5 K(Mult) 50 K (single)	(B) 200 (O) 500	(O) 250 (M) (O) 400 (S)
500	26.2	667	50 K	50 K (Mult) 80 K (single)	B) 200 (O) 710	(O) 400 (M) (O) 630 (S)

A comparison of the operating times for a range of fuse sizes subjected to a 1100 A fault current is shown in Table 4. The operating times vary from 0.25 secs for a 160 A fuse to 40 seconds with a 400 A fuse.

Table 4 – Operating times on LV HRC fuses for a 1100 A fault current

LV HRC Fuse Size (A)	Operating Time (s)
160	0.25
250	2
300	6
400	40

7.2 Introduction of the 3/10 K or 6/20 K fuses for transformers less than 100 kVA

The current practice for 11 kV EDO fusing at ENERGEX for single phase and three phase transformers from 10 kVA to 100 kVA is to use a 8T fuse. A number of utilities, such as Ergon Energy and Country Energy are now using dual range fuses, such as a 3/10 A, or 6 / 20 A for the smaller transformers. The 3 / 10 A fuse has a 3A characteristic for low values of current, and a 10A characteristic for larger values of current. These fuses have successfully been used in applications where lightning surges cause operation of Standard 3A K type elements.

Ergon Energy uses the 3/10 K fuses for single phase 10 kVA transformer and 3 phase 25 kVA transformers and 6 / 20 A fuses for 25 kVA single phase transformers 50 and 63 kVA three phase transformers.

The drawback with the introduction of the dual fuse range is the lack of coordination between upstream reclosers. Ergon advises that the 3/10 A fuse cannot be guaranteed to coordinate with an upstream recloser with a coil size smaller than 10 A whilst with the 6 / 20 A fuses, coordination may be obtained when the upstream recloser has a coil size smaller than 15 A. This is not likely to be a concern to ENERGEX, because, the overcurrent trip settings are typically above 100 A and the earthfault trip settings at 20 A or above.

7.2 Introduction of the HRC or Fault Tamer fuses for high fault current circuits

On the ENERGEX network, there are a number of zone substations which have fault levels up to 13 kA close to the substation. EDO fuses are rated only at 8 kA and special care must be taken if pole mounted transformers are located close to the high current zone substations.

Ergon is using HRC current limiting fuses where the fault currents exceed 8 kA. Table 2 shows that for a 100 kVA transformer, the HRC fuse is 12 A without LV fusing and 18 A with LV fusing. Country Energy on the other hand is using either a Fault Tamer of SMD fuse (refer to Appendix 1 for definitions). Both of these fuses are manufactured by the S&C company and are rated to a fault breaking capacity of 12 kA.

One of the other main advantages with the use of HRC fuses is that it avoids one of the major concerns with the operation of EDO fuses - the possible ignition of ground fires from the emission of incandescent particles.

8.0 CONCLUSIONS AND RECOMMENDATIONS

A survey of low voltage protection practices throughout Australia indicates that there is an opportunity for ENERGEX to improve the effectiveness of its low voltage overhead network protection systems. Although only 5 utilities have responded, there is universal support for the installation of LV fuses across the range of transformer sizes.

The main findings in this investigation are:

(1) ENERGEX needs to further consider the ENA low voltage protection guidelines which stipulate for overhead lines *“Overhead distributors shall be designed and incorporate electrical protection designed to clear a bolted fault, such as, wires twisted or firmly held together by fallen tree branches.”* There have been instances on the ENERGEX network, where bolted faults have not been cleared by the HV EDO protection.

(2) Low voltage fusing can provide significant benefits in safety and reliability. Low voltage fusing can also reduce the risk of damage to transformers by clearing for faults which are not cleared by the 11 kV EDO fusing. Reliability on the low voltage network can be increased be fusing individual circuits. The loss of supply to customers can be reduced by having more circuit individually fused. There is also an improvement in clearing times expected when circuits are individually fused due to the smaller size of fuses being employed.

(3) The main disadvantages with the introduction of low voltage fuses are the additional cost for the fuses (estimated incremental cost of $100 for a replacement of a disconnect link with a switch fuse unit and $720 per additional single fuse installation) and the slowing of the EDO clearing times. The increase in the operating current for the EDO fuses are modest when compared to the anticipated fault levels on the 11 kV network.

(4) There are significant advantages with introducing high current rating EDO fuses, such as the HRC, Fault Tamer or SMD types to address the increase in fault levels on the 11 kV network. Current EDO fuses are rated at 8 kA and the HRC, Fault Tamer or SMD types can handle fault currents up to 12 kA. There is an increased cost with these types of fuses, but one of the significant advantages is the containment of the hot fuse elements thereby eliminating the possibility of a ground fire.

The main recommendations of this investigation are:

(1) ENERGEX should change it's low voltage protection philosophy to align with best practice in Australia and in line with the ENA low voltage protection guidelines and introduce low voltage fusing across all transformer sizes.

(2) ENERGEX should adopt a single fuse installation adjacent to the transformer for all of the low voltage circuits but allow for the flexibility of fusing 2 or more low voltage circuits emanating from the transformer in special cases. There are considerable benefits in terms of reliability when individual LV circuits are fused.

(3) ENERGEX should consider the use of 12 kA rated EDO fuses such as the HRC, Fault Tamer or SMD type fuses to address the increase in fault levels and support our bush fire risk mitigation strategies.

(4) Systems Engineering should develop a Distribution Transformer Fusing Standard like Country Energy to outline the philosophy and rationale for the selection of fusing.

9.0 REFERENCES

1. ESAA Application Guide D(b) 20-1976 “Fuse Protection of Transformers”.

2. ENA Low Voltage Protection Guideline – March 2006

APPENDIX 1

Definition of Terms used in Report:

EDO: (Expulsion Drop-Out fuse) A non-current limiting fuse usually taking a number of cycles to interrupt the current after the fuse element has melted. These typically consist of a fuse element surrounded by air inside a hollow tube (fuse carrier). Upon operation, the fuse element melts and the carrier mechanically unlatches and swings down providing electrical separation and visual indication of fuse operation. Typically these are rated only up to 8kA based on the fault rating of the fuse carrier.

Fault Tamer Fuse: A ‘drop-out’ style fuse assembly with both a conventional fuse element and a backup current-limiting fuse element in series. These units are rated to a fault breaking capacity of 12kA and may be used in lieu of standard EDO’s where fault levels are higher than 8kA. The current limiting element also provides sub-cycle operation for high level faults, thus minimising voltage sags and loss of voltage sensitive equipment on the surrounding network.

Dual-Range Fuse: A fuse element with a modified TCC that resembles two different fuse ratings e.g. A 3/10A fuse has a 3A characteristic for low values of current, yet exhibits a 10A characteristic for larger values of current. These fuses have successfully been used in applications where lightning surges cause operation of Standard 3A K type elements.

SMD Fuses: An EDO style fuse link manufactured by S&C Company that uses an arc quenching medium inside the fuse unit to minimise arc energy and exhaust during operation. This design allows higher fuse ratings and fault ratings than normally achievable with standard EDO fuse links. SMD20 units are recommended for use with Distribution style transformers at 11kV and 22kV and can handle fault levels of 12kA and above depending on voltage and system X/R ratios (refer to manufacturers’ documentation).

LV HRC fuses: High rupturing current fuses which have pre-arcing characteristics which are generally above 180% of nominal fuse rating. When set at the nominal rating of the transformer, will be able to handle the 150% of overloading.

APPENDIX 2 – FUSE RATING PHILOSOPHY OF COUNTRY ENERGY AND ENERGY AUSTRALIA

PHILOSOPHY ADOPTED BY COUNTRY ENERGY

The philosophy adopted in selecting fuse ratings for a given size transformer is detailed as follows:

1. Determine LV nominal current for transformer.
2. Select LV fuse based on nominal LV current. Generally, fuse ratings were selected to be of the order 95-100% of calculated LV nominal current.
3. Calculate HV nominal current for transformer.
4. Select HV fuse based on the following:
   a. HV fuse pre-arcing curve to coordinate above transformer inrush and cold load pickup curve (2xIn @100s, 3xIn @10s, 5xIn @1s, 8xIn @0.1sec, and 12xIn @0.01s. Note the last three xIn values were modified from suggested values of 6, 12, and 25 respectively. Modification based on consideration that transformers are in 5-500kVA range, and have lower peak inrush currents than larger units).
   b. HV fuse pre-arcing curve to coordinate above LV fuse total clearing time2 for LV phase-phase fault (LV fuses modelled were Bussmann NH series and GEC 'T' type fuses).
   c. Where possible, HV fuse total clearing time to coordinate below transformer damage curve (typical inrush curve characteristic defined in ANSI/IEEE Std 242-1986 for Category I transformers 5-500kVA) 2.
   d. HV Fuse clearing time for Transformer LV Earth Faults to be ideally <1sec, but no slower than 3 seconds.

Notes: Rating of LV fuses below the nominal output of the transformers (typically 95%) was deemed acceptable given that the LV HRC fuses have pre-arcing characteristics that are not defined below 180% of nominal fuse rating. This effectively covers the 5% variation below nominal as well as short term overloads to 150%. These LV Fuse ratings (for type gL/gG fuses) were also recommended by fuse manufacturers in their catalogues.

PHILOSOPHY ADOPTED BY ENERGY AUSTRALIA

5.15 SUMMARY OF THE MORE IMPORTANT FACTORS ON WHICH A TRANSFORMER FUSING POLICY SHOULD BE BASED

(a) The voltage rating should be appropriately related to the transformer's operating voltage.

(b) The current rating (in the absence of an alternative plant rating policy) should permit loading to 1.8 x the transformer's nameplate rating without exceeding permissible temperature limits on the fuses or the associated equipment. (Generally requires the use of low resistance current-limiting fuses particularly when they are housed in equipment which restricts cooling.)

(c) The breaking capacity should exceed the system's prospective fault level under normal, and preferably also abnormal, operating conditions.

(d) The pre-arcing time-current characteristic should permit discrimination with the "largest" secondary circuit fuse or other protective device likely to be associated with the transformer to be protected for the most unfavourable fault condition, e.g. Ø-Ø fault on Dy transformer. The actual characteristic should not fall outside ±10% of the maker's published curve. Generally a tighter tolerance, e.g. ±5% is preferable.

(e) The operating time for a current corresponding to the most onerous secondary terminal short circuit, e.g. Ø-n fault on Dy transformer, should not exceed one second.

(f) The minimum breaking current should not exceed the 100 second melting current.

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Systems Engineering Memorandum

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Date	10 July 2008 **Reference** SEG-08-9A
Subject	**CHANGE TO DISTRIBUTION FUSING STANDARD – INTRODUCTION OF LOW VOLTAGE FUSES FOR TRANSFORMERS ABOVE 100 KVA**

1.0 CURRENT STATUS OF FUSE PROTECTION ON LOW VOLTAGE FEEDERS IN ENERGEX

In ENERGEX, low voltage overhead feeder protection is provided by low voltage high rupturing current (HRC) fuses for transformers rated less than 100 kVA and 11 kV Expulsion Dropout (EDO) fuses for pole mounted distribution transformer at or above 100 kVA.

For the larger distribution transformers, the 11 kV EDO fuse rating is selected to handle the maximum anticipated transformer load, which is 1.5 times the transformer nameplate rating. With transformers rated at or below 100 kVA, the fuse rating has been standardised across the range of transformer sizes at 8A. The purpose of the larger fuse rating is to prevent nuisance operation of the fuses due to lightning surges.

Low voltage fuse protection is also provided on all underground cables and overhead bundled cable circuits (LVABC). Fuses are provided on underground cables to prevent damage to the insulation from a sustained fault. The fuse protection for the LVABC is provided to protect the cable from thermal overloads which may affect the integrity of the insulation and cause the cable to slip out of the terminations.

2.0 ENA NATIONAL LOW VOLTAGE PROTECTION GUIDELINES

The most recent version of the ENA National Low Voltage Protection released in March 2006 outlined the principles for low voltage protection as follows:

<u>For overhead lines</u>

"Overhead distributors shall be designed and incorporate electrical protection designed to clear a bolted fault, such as, wires twisted or firmly held together by fallen tree branches."

In reality, there will always be a contact resistance at the point of the fault. Low voltage faults often involve tree branches applying pressure to the conductors or wildlife bridging conductors, thereby causing phase to phase or phase to neutral faults to occur. To cover situations where there is a finite contact resistance, the ENA guideline goes on further to say:

"As it is not possible for electrical protection on LV distributors to detect some faults, such as LV arcing faults or wires on the ground, alternative means of risk mitigation must be considered and adopted"

3.0 PROPOSAL TO INTRODUCE LOW VOLTAGE PROTECTION FOR TRANSFORMERS GREATER THAN 100 KVA

3.1 Fusing Practices at Ergon Energy and Other Utilities

Ergon Energy undertook a review of the low voltage protection a number of years ago and found there were significant benefits in adopting low voltage fusing for the larger transformers. The benefits found by Ergon Energy were:

- Prevention of damage to transformers from thermal overloads (Ergon Energy experienced thermal overload on transformers following cyclones when the LV conductors were wrapped around each other and were not cleared by the EDO fuses)
- Prevention of damage to LV circuits from faults at the end of these runs that are not cleared quickly by the HV protection
- Extends the protective reach on the low voltage circuits for bolted faults
- Ensure that the utility is seen as doing all that was reasonable with regards to public safety

A small survey of a number of utilities in Australia (5 respondents) has found that low voltage fusing is adopted as a Standard across the range of distribution transformers.

3.2 Improvement in Public Safety

There have been incidences on the ENERGEX network where low voltage phase to earth faults have not been cleared by 11 kV EDO fuses with a consequence of substantial property damage. One particular instance occurred in 2003 at Norman Park where a wind blown palm frond caused an A phase to neutral fault. The 20 A EDO fuses on the 200 kVA transformer supplying the low voltage circuit did not clear the low voltage fault.

The fault current caused the A phase and neutral conductors to weld together and the sustained fault current caused neutral connections on bridges to be badly damaged. A number of houses (up to 13) suffered property damage, particularly at the switchboard and the earth connections (where the high earth fault current flowed to ground). A number of loss of supply/ dim lights were reported at the time of the fault and the crew isolated the transformer about 80 minutes after these reports to limit the damage.

If there was a low voltage HRC fuse installed at the transformer or down the low voltage circuit, then it is likely that the neutral and the houses may not have suffered any damage.

3.3 Protection of transformer from overload situations

Ergon Energy has experienced thermal overload on transformers following cyclones when the LV conductors were wrapped around each other and were not cleared by the HV fuses.

Low voltage faults which generate low fault currents, such as phase to earth, tend to have some contact resistance (eg tree branch or wildlife) and this will significantly reduce the fault currents to below the overload capability of the transformer.

By employing low voltage fuse protection on the transformer it can offer some degree of overload protection on the transformer for uncleared bolted low voltage faults.

4.0 COST FOR THE INTRODUCTION OF LOW VOLTAGE FUSE PROTECTION ON LARGER TRANSFORMERS IN ENERGEX

4.1 Material and Installation costs

If low voltage fusing is introduced for the larger transformers, there are 2 options to fuse the outgoing open wire circuits. One option involves the installation of only one set of LV fuses at the transformer, the other option is to install separate fuses on all of the outgoing low voltage circuits. The estimated cost for the installation of a set of low voltage fuses is around $750 (which includes material and installation).

The incremental cost for the first fuse unit is however much less than this because the current standard has disconnect links at the transformer. It will only be a matter of installing a switch fuse unit instead of a disconnect link. The cost of installing the fuses would be around $100.

4.2 Requirement to ensure grading of 11 kV and low voltage protection

If low voltage fuses are to be introduced for the larger distribution transformers, then there will need to be discrimination applied between the 11 kV EDO's and the low voltage HRC fuses. Otherwise, in the event of a fault on a low voltage circuit, both sets of fuses will operate and will need replacement.

It is anticipated that there will be a need to increase the size of the 11 kV EDO fuse when LV fusing is introduced. The drawback with the increase in fuse size, is that the EDO fuses will operate in a slower time and this will allow more damage to occur on the transformer and it's associated components (terminations, cabling etc).

5.0 RECOMMENDATIONS

There is an opportunity for ENERGEX to improve the effectiveness of its low voltage overhead network protection systems. The following recommendations are made to the distribution transformer fusing standards:

(1) ENERGEX change it's low voltage protection philosophy to align with best practice in Australia and in line with the ENA low voltage protection guidelines and introduce low voltage fusing across all transformer sizes.

(2) The change in the Standard to be applied at the distribution transformer on all new overhead low voltage feeders or where there is an upgrade of the transformer or there is a re-conductoring of the low voltage conductor

(3) ENERGEX undertake a retrofit program to upgrade low voltage fusing on existing transformers.

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